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Influence of air-assistance on spray application for tomato plants in greenhouses

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A B S T R A C T

Protected horticulture production represents one of the most important agricultural businesses in Southern Europe. However, many problems related to the lack of mechanisation, intensive use of pesticides, and, in some cases, undesirable residues on food, have not been solved yet. In this context, application technology is a key factor for the improvement of the efficacy and efficiency of plant protection products. Spray guns and knapsack sprayers are the most common technologies that have been used for this purpose. However, several studies have demonstrated that, compared with spray guns, the use of vertical boom sprayers in greenhouses improves spray distribution and reduces labour costs and operator exposure. The main objective of this study was to evaluate the influence of air-assistance on spray application in conventional tomato greenhouses. For this purpose three different spray conceptions were evaluated: 1) a modified commercial handheld trolley sprayer with two air assistance concepts; 2) a self-propelled sprayer; and 3) an autonomous self-propelled sprayer with remote control. All the sprayers considered were evaluated in terms of absolute and normalised canopy deposition, uniformity of distribution, and losses to the ground. In addition, the vertical liquid and air velocity distributions of the sprayers were assessed and compared with the canopy profiles and spray depositions. Yellow tartrazine (E-102 yellow) was used as a tracer for deposition evaluation. The results indicated that increasing the air velocity does not increase the efficiency of a spray application. In general, the modified handheld trolley sprayer showed the best results in terms of deposition and uniformity of distribution, especially at the lowest air assistance rate. These results were confirmed with evaluation of the uniformity of the air and liquid distribution.

1. Introduction

One of the most hazardous factors affecting the economic, environmental and productivity parameters in protected horticultural production involves the use of plant protection products (PPP) for pest/disease control. Operator safety, residues on produced food, environmental contamination and economic investment are the problems related to this specifically as well as labour requirements, and most of them are directly linked to the technology used during the process (Nilsson and Balsari, 2012). At the same time, covered horticulture production represents one of the most important agricultural businesses in Southern Europe, focused mainly in Spain, Italy, and France (EFSA, 2010). However, many unsolved problems exist related to the lack of mechanisation, intensive use of PPPs (Nuyttens et al., 2004a; Céspedes et al., 2009), and undesirable residues on food (van Os et al., 2005).

In recent years, there have been important improvements in spray technology, with considerable differences depending on the target crops. Manufacturers of field crop and orchard sprayers have progressively introduced new and improved devices, taking advantage of the latest developments in computers, electronics,

Abbreviations: PPP, plant protection products; DISAFA, Dipartimento di Scienze Agrarie, Forestali e Alimentari; LAI, leaf area index; LWA, leaf wall area; TRV, tree row volume; LAD, leaf area density; ANOVA, analysis of variance; HSD, honest significant difference; SEM, standard error of the mean.

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and global positioning systems. Those improvements have led to a safer and more effective use of pesticides, reducing the risk of contamination, adapting the proper dose to the canopy structure (Gil et al., 2007, 2011; Siegfried et al., 2007; Zhou et al., 2012) and improving traceability. However, the improvements have not been implemented as quickly in the case of spray application techniques used in greenhouses, where handheld sprayers or knapsack sprayers are still very popular (Nuyttens et al., 2004b; Balloni et al., 2008; Nilsson and Balsari, 2012; Sánchez-Hermosilla et al., 2013). The use of such primary technologies leads to limited efficacy and efficiency of pesticide application, with high risk of operator exposure (Nuyttens et al., 2009).

Alternative spraying techniques to handheld sprayers have been developed and tested in the past few years. Several studies have already demonstrated that the use of vertical boom sprayers in greenhouses improves spray distribution (Nuyttens et al., 2004a; Sánchez-Hermosilla et al., 2012) and reduces labour costs and operator exposure (Nuyttens et al., 2004b, 2009) in comparison with spray guns. Other researchers have investigated automatic spraying on PPP using new technologies such as navigation systems and autonomous vehicles with ultrasonic sensors or machine vision (Mandow et al., 1996; Sammons et al., 2005; Subramanian et al., 2005; González et al., 2009; Balsari et al., 2012; Sánchez-Hermosilla et al., 2013). However, according to Sánchez-Hermosilla et al. (2012), the use of such vehicles is very limited because of the high costs involved.

Air assistance has been considered one of the key elements for improving the efficiency of the spray application process in greenhouses, especially for dense crops (Llop et al., 2015). Derksen et al. (2007) achieved higher spray coverage on lower surfaces of bell pepper leaves using air-assisted delivery with single-fan nozzles than when using conventional delivery with either twin-fan or air induction nozzles. Similar results were obtained by Braekman et al. (2010) and Abdelbagi and Adams (1987). However, although air assistance has proven to be important for improving deposition on the canopy, it is still necessary to investigate the air distribution according to the canopy structure and the optimal relationship between the vertical distributions of the three factors affecting deposition, namely canopy surface, air velocity profile, and liquid distribution. Improvements in the uniformity of deposition have been achieved through optimum relationships between those parameters in several vertical crops such as vineyards (Pergher and Gubiani, 1995; Gil et al., 2013), citrus (Pai et al., 2009; Khot et al., 2012), and orchards (Landers et al., 2012).

Along with the new and improved technologies, the working parameters selected for the spray application processes (mainly volume rate and pressure) are also important factors affecting the final success. A survey of greenhouse farmers in the Netherlands (Goossens et al., 2004) showed that 90% of growers used high-pressure spray equipment (i.e. spray guns or lances) to apply PPPs, even though spray boom equipment has become increasingly popular. Braekman et al. (2009) confirmed that growers were convinced that high application rates and spray pressures are indispensable for obtaining satisfactory coverage and sufficient penetration. Moreover, van Zuydam and van de Zande (1996) reported that the condition of the average spraying equipment used in daily practice is variable and usually not of a high standard.

The main objective of this research was to investigate the effect of air-assistance on different spray application techniques, ranging from manually pulled trolley sprayers to autonomous sprayers, on the spray deposition on tomato plants grown in greenhouses. Additionally, the effect of air velocity and nozzle pattern on canopy deposition, uniformity, and losses to the soil were also assessed.

2. Materials and methods

2.1. Spraying equipment

Three air-assisted sprayers adapted to greenhouse conditions were tested (Fig. 1). These three sprayers were used for four independent treatments as the first sprayer, a research prototype derived from a commercial handheld trolley sprayer, was converted into two different versions equipped with different blower units. Consequently, four different treatments (T1 to T4) were tested.

2.1.1. Modified prototype of handheld trolley sprayer (used for treatments T1 and T2)

The modified prototype T1 was a modification of a commercial handheld trolley sprayer (Carretillas Amate, Almería, Spain) with two vertical booms that could be adjusted to the canopy width and had six nozzles per side spaced at 0.35 m intervals. This modified sprayer (Fig. 1a) was fitted with an air-assistance device (average air velocity of 19.3 m s^{-1}) composed of an air generator (Nuvola 5HP, Cifarelli S.P.A., Voghera, Italy) activated by a 3.68 kW engine, a central air collector, and six individual spouts fitted parallel to each nozzle.

The modified prototype T2 (Fig. 1b) consisted of the same handheld sprayer as previously mentioned, but equipped with a different blower (B&D 3000W, Stanley Black & Decker Inc., New Britain, UK) with an air velocity of 14.0 m s^{-1} (average of values measured at each air outlet surface). This blower had an electric engine connected to a cable attached to the feeding pipe following the specifications described by Llop et al. (2015).

Both sprayers (T1 and T2) were fed using a pipe connected to an external sprayer through a piston pump with a tank of 100 L capacity.

2.1.2. Sagevi sprayer (used for treatment T3)

A self-propelled sprayer Atom 120 (Sagevi, Vilassar de Dalt, Spain), with air assistance, 120 L tank capacity, and four nozzles per side mounted in pairs, was also tested (Fig. 1c). The first pair of nozzles was located 0.59 m from the ground, and the second one was on an adjustable mast with a height range of 1–2 m that could be varied using a hydraulic piston activated by the operator. The distance between the two pairs of nozzles was 0.7 m, and the nozzles were fitted inside individual air outlets.

2.1.3. Self-propelled sprayer (used for treatment T4)

A Unigreen self-propelled sprayer mounted on a platform with remote control, developed in collaboration with Unigreen (Maschio Gaspardo S.p.A., Campodarsego, Italy) and DISAFA (Dipartimento di Scienze Agrarie, Forestali e Alimentari) (University of Turin, Italy), was also selected for the field trials. The prototype (Fig. 1d), described in detail in Balsari et al. (2012), has a 150 L capacity tank with two vertical booms and four nozzles on each side located at 0.45 m intervals. The air-assistance device consisted of an electric axial fan blower connected to a vertical air sleeve with several outputs per side.

2.2. Canopy characterisation

The experiments were conducted at Viladecans (Barcelona, NE Spain) in a commercial tomato (*Solanum lycopersicum* L. cv. Barbastro) greenhouse of 1265 m^2 (composed of a main corridor with several aisles on each side) located in a typical field farming area of this region.

The tomato plants had an average canopy height of 1.96 m and average width of 1.07 m. The plants were dispersed in a twin row system (two plants close together) with 2 m aisle width, 0.4 m